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(54) Abstract Title
Variable speed generator arrangement and control

(57) The arrangement comprises a heat engine (12) driving a generator (14) through a transmission (18) which is arranged to vary the input speed of the generator (14) with respect to the speed of the engine (12). The transmission ratio is either stepped or continuously variable and is controlled by a controller (20) to achieve desired engine efficiency in response to prevailing operating conditions presented to the generator. The generator arrangement may be used as part of a series hybrid powertrain of a vehicle (10) which provides power to a set of traction motors (1).

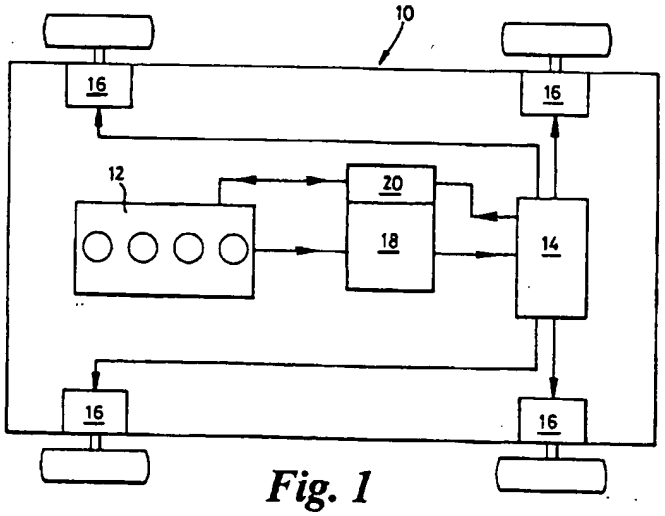

Fig. 1

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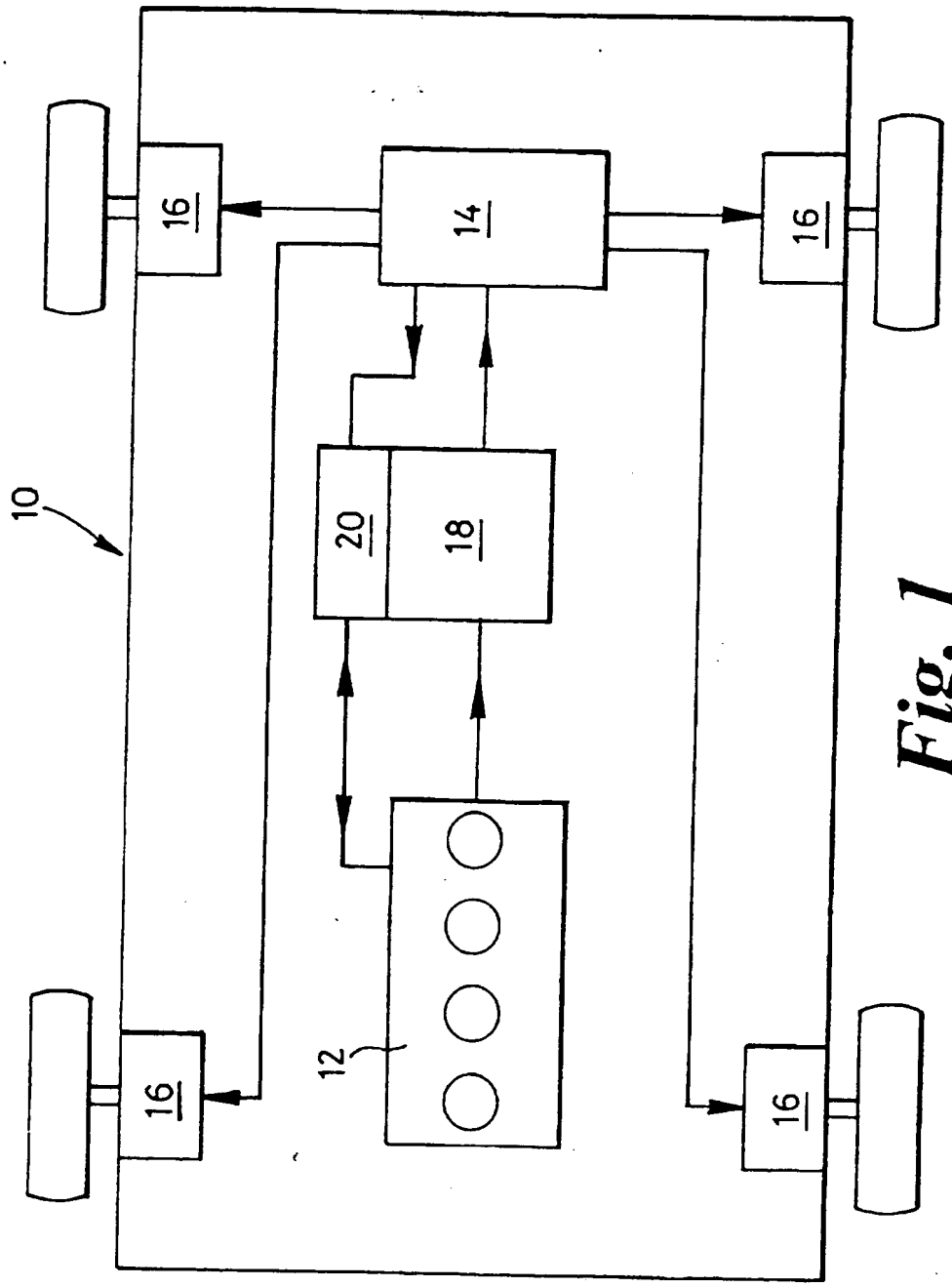

Fig. 1

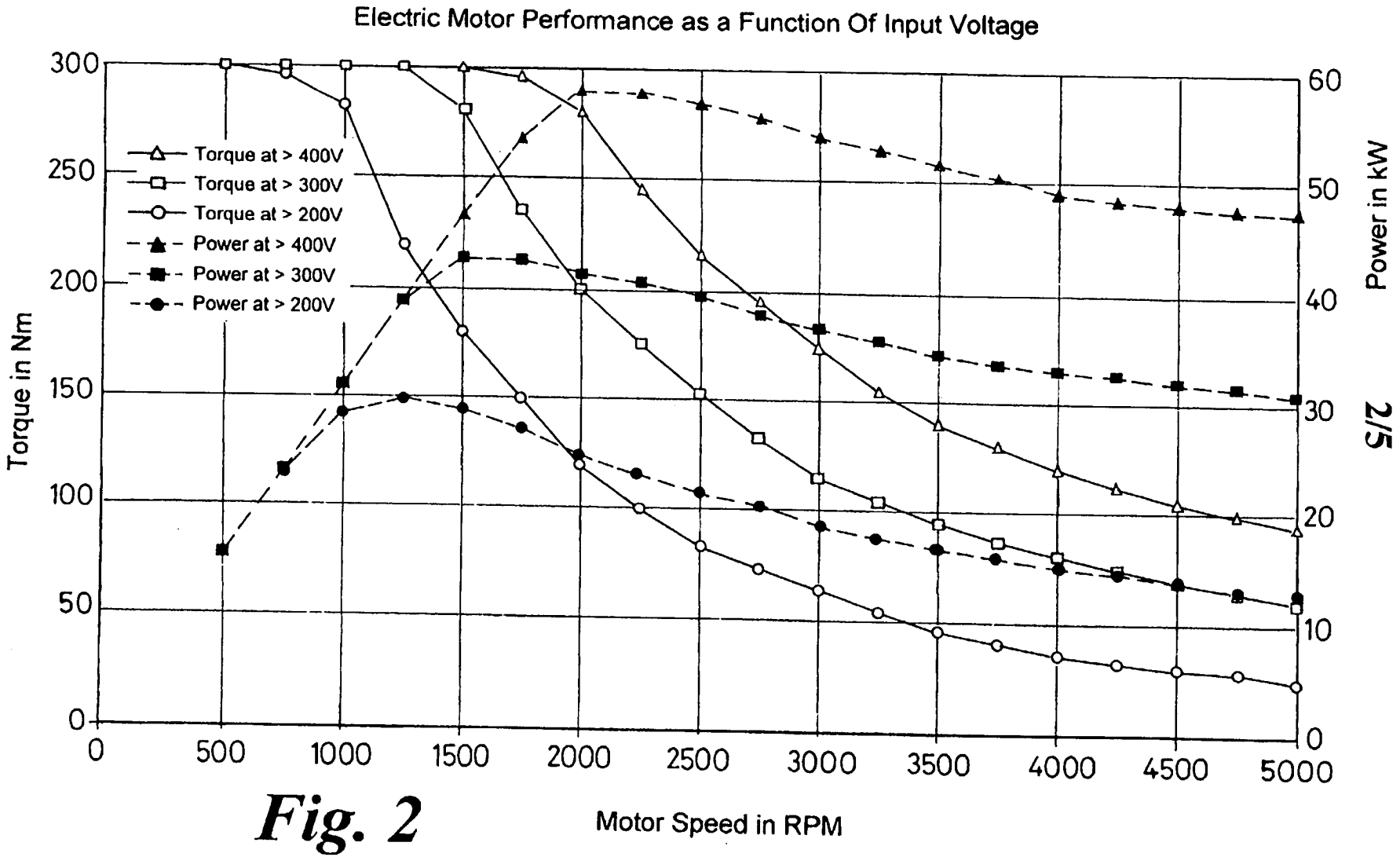
Electric Motor Performance as a Function Of Input Voltage
Torque at > 400V
Torque at > 300V
Torque at > 200V
Power at > 400V
Power at > 300V
Power at > 200V
Torque in Nm
Power in kW
Motor Speed in RPM
0
50
100
150
200
250
300
0
10
20
30
40
50
60
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Fig. 2

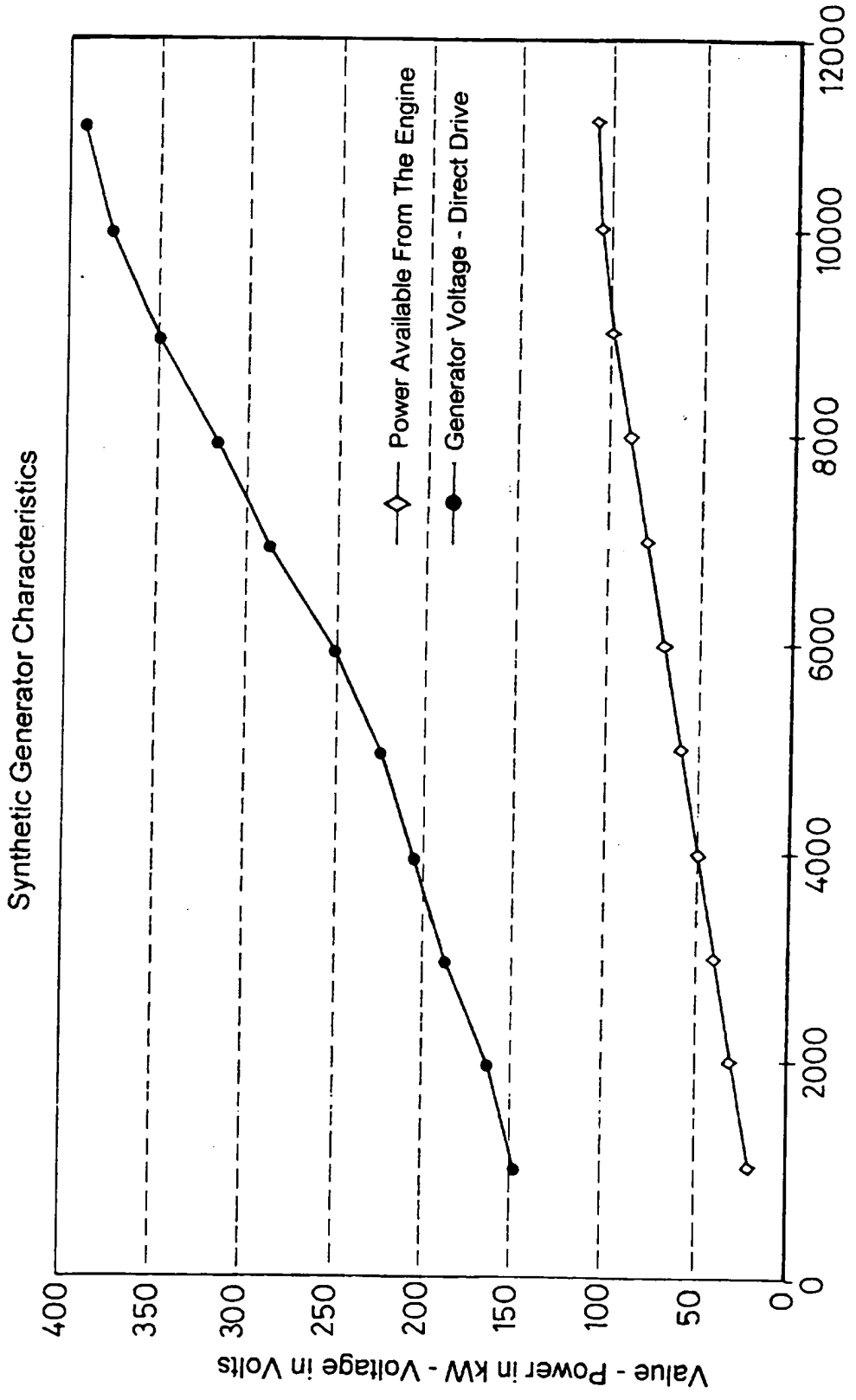
Synthetic Generator Characteristics
Power Available From The Engine
Generator Voltage - Direct Drive
Value - Power in kW - Voltage in Volts
Engine speed in rpm
0
50
100
150
200
250
300
350
400
0
2000
4000
6000
8000
10000
12000

Fig. 3

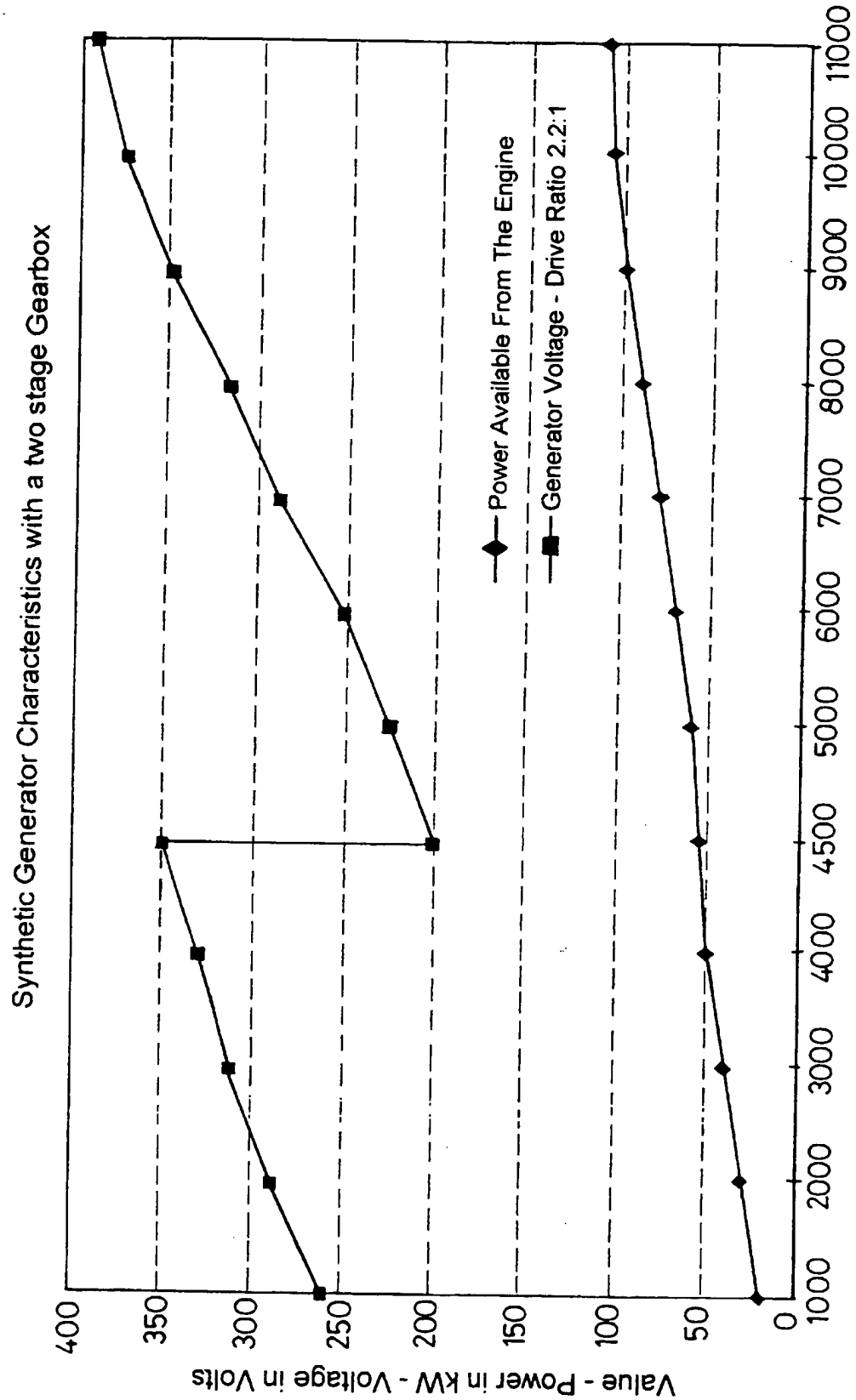
Synthetic Generator Characteristics with a two stage Gearbox
Value - Power in kW - Voltage in Volts
Engine Speed rpm
Power Available From The Engine
Generator Voltage - Drive Ratio 2.2:1
400
350
300
250
200
150
100
50
0
1000
2000
3000
4000
4500
5000
6000
7000
8000
9000
10000
11000

Fig. 4

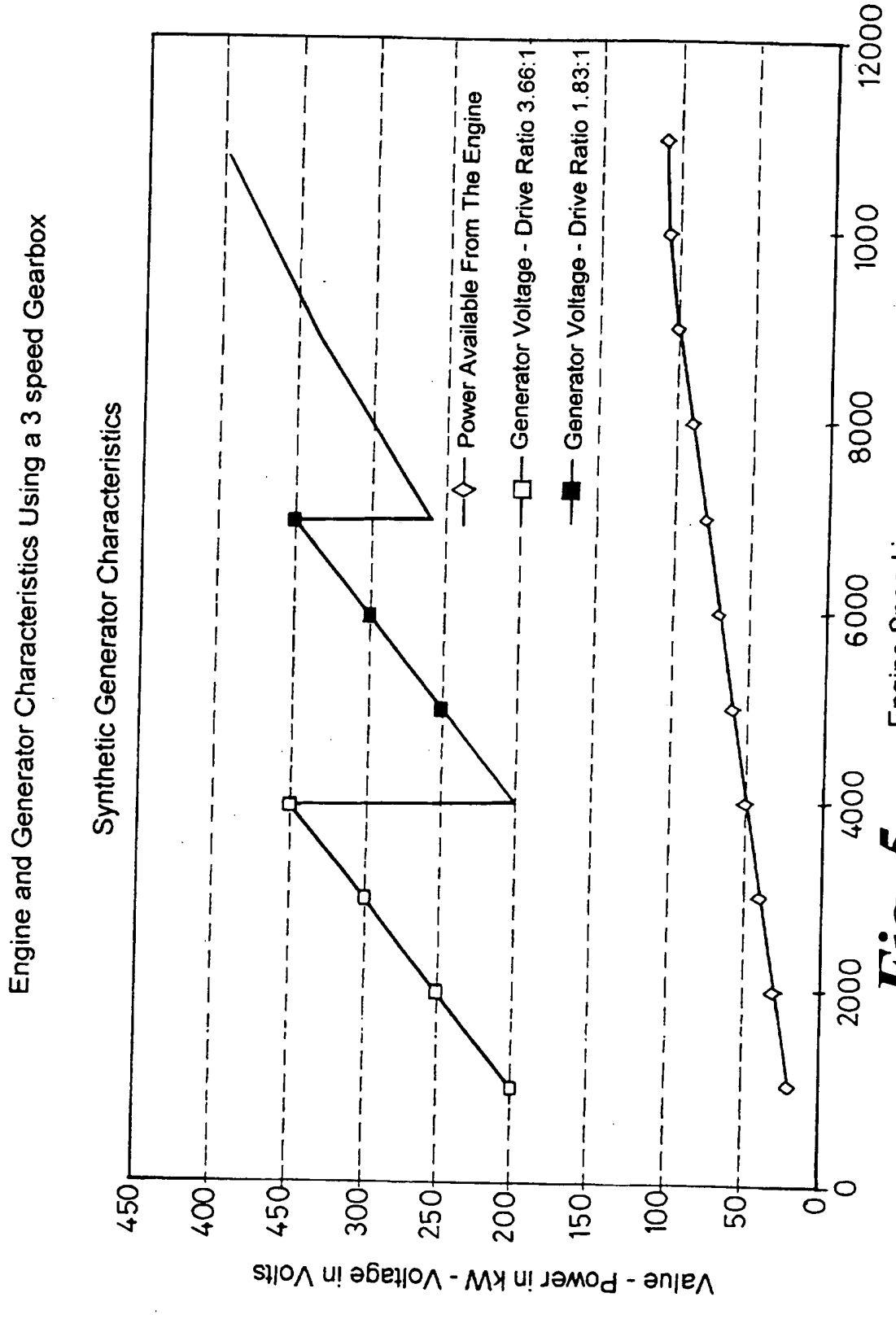
Engine and Generator Characteristics Using a 3 speed Gearbox
Synthetic Generator Characteristics
Power Available From The Engine
Generator Voltage - Drive Ratio 3.66:1
Generator Voltage - Drive Ratio 1.83:1
Value - Power in kW - Voltage in Volts
Engine Speed in rpm
450
400
450
300
250
200
150
100
50
0
0
2000
4000
6000
8000
1000
12000

Fig. 5

A Generator

This invention relates to generators and in particular to a generator including a heat engine and an electrical machine. The invention also relates to a vehicle including such a generator.

It is known to provide a vehicle with a series hybrid powertrain in which an engine drives an electrical machine so as to produce electrical power for one or more traction motors. The electrical power which can be generated by such a generator set may be limited by the maximum input speed to the electrical machine. That speed is often defined by the maximum available engine speed or the voltage limit of the machine.

It is an object of this invention to provide an improved generator and also to provide a vehicle including such a generator.

According to the invention there is provided a generator for producing electrical power, the generator comprising a heat engine arranged in use to drive an electrical machine, wherein the engine is coupled to the electrical machine through a transmission unit which is arranged in use to vary the input speed of the electrical machine with respect to the speed of the engine in order to match the input speed of the electrical machine to provide a power output suitable for prevailing operating conditions and the input speed of the electrical machine being one of a set of input speeds for the

electrical machine consistent with pre-determined generator responses to current or a sequence of prevailing operating conditions presented to the generator in order to achieve desired engine efficiency and/or noise level for necessary engine response to generate the input speed for the electrical machine.

The transmission may be arranged to selectively provide an increase in the generator input speed for a given engine speed and may be arranged to effect a substantially stepped change in the input speed of the generator through increments of the input speeds which form the set of input speeds for the electrical machine under a predetermined set of conditions.

The transmission may comprise a continuously variable transmission which may be selectively arranged to vary the input speed of the generator in a substantially continuous manner or by simulated substantially fixed ratios.

The ratio between the engine speed and the input speed of the electrical machine may be controlled automatically by a controller.

The generator may comprise a series hybrid powertrain of a vehicle.

The invention also provides a controller for a generator according to the invention and a vehicle including a generator according to the invention.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a vehicle including a generator according to the invention;

Figure 2 is a graph of the performance of a traction motor of the vehicle of Figure 1 as a function of its input voltage;

Figure 3 is a graph comparing the power available from an engine of the vehicle of Figure 1 with the voltage available from an engine driven generator of that vehicle;

Figure 4 is a generator characteristic of the vehicle of Figure 1 according to a first embodiment of the invention; and

Figure 5 is a depiction of generator characteristics of the vehicle of Figure 1 according to a second embodiment of the invention.

Referring to the figures, a vehicle 10 includes a hybrid powertrain comprising a heat engine 12 and an electrical machine 14 which co-operate

to produce electrical power for a set of traction motors 16. The engine 12 drives the electrical machine 14 at an input speed through a transmission 18 which is under the control of a controller 20 to achieve the desired input speed for the electrical machine.

The controller 20 controls the transmission 18 in response to feedback from the engine 12 and the electrical machine 14 to vary the ratio between the speed of the engine 12 and the input speed of the electrical machine 14. The controller 20 responds to feedback from the engine 12 which is indicative of the power available from the engine 12 and of the engine speed and also to feedback from the electrical machine 14 which is indicative of the electrical power that it is generating. The ratio between the engine speed and the input speed of the transmission 14 is varied automatically by way of stepped changes in the ratio consistent with a set of input speeds for the electrical machine.

With particular reference to Figure 2, it can be seen that the torque produced by the traction motors 16 is related to the voltage they are supplied by the electrical machine 14. That voltage in turn is substantially dependent upon the input speed to the electrical machine presented through the transmission 18.

In Figure 3 it can be seen that where direct drive between the engine 12 and the electrical machine 14 is used, the voltage generated by the electrical machine 14 is proportional to the speed of the engine 12 driving it. The voltage output of the electrical machine 14 is set by individual machine design and is therefore limited in its ability to provide useful output to a substantially fixed speed range.

To achieve maximum performance from the generator 12, 14, 18 of a series hybrid vehicle 10, the value and stability of the supply voltage from the electrical machine 14 needs to be matched closely to demands of its associated traction motors 16 and that demand is set by a user.

As generated voltage is proportional to the rotational speed of the generator 14 and thus the engine 12, to achieve a high voltage requires a high input speed for the electrical machine 14. Where direct drive is used, however, the performance of the engine 12 is optimised to give best fuel efficiency, lowest emissions and low noise.

The graphs of Figures 2 and 3 show that there is a constraint on hybrid vehicles which only use direct drive between the engine 12 and the electrical machine 14 because there is a voltage limit at a given power demand. For example, for a power demand of 50 kilowatts in Figure 2 it can be seen that this power can be developed by the engine at 4000 rpm. The problem with

this speed is that it generates a voltage of about 210 volts which, when applied to the motor characteristic seen in Figure 3 and assuming that the vehicle 10 is cruising at mid-speed, gives a traction motor power of 25 kilowatts which is considered to be below the target requirement for the vehicle 10. To achieve the required power output at this speed, the traction motors 16 would require an input voltage of approximately 350 volts. When this is extrapolated back to the generator characteristic of Figure 2, 350 volts would be achieved at an engine speed of 9000 rpm. To run the engine 12 at this speed would be likely to mean operating it away from its point of maximum efficiency. Running the engine 12 at such high speeds could also incur unacceptable noise penalties.

The problem described above is particularly important in series hybrid vehicles that are used in an off-road environment, where vehicle speeds are low but the torque required to negotiate the terrain can be high. In this scenario, to provide maximum performance with a higher engine speed would result in a very noisy vehicle 10 which could also have non-optimised fuel economy and emissions, these factors being contrary to the perceived demand for "tread lightly" off-road vehicles.

The inclusion of a transmission 18 between the engine 12 and the electrical machine 14 in accordance with this invention allows a variation in the speed of the input shaft of the electrical machine 14 with respect to

engine speed and allows the controller 20 to perform independent manipulation of the engine characteristics to suit the prevailing conditions, for example, good fuel economy and noise levels whilst cruising at speed.

In a first embodiment of the invention a two-stage gearbox is used and the generator characteristic this produces can be seen in Figure 4. Considering the traction condition described above, a 50 kilowatt load at 350 volts can be generated at a much lower engine speed, i.e. using the transmission 18 the speed of the engine 12 can be brought down to 4500 rpm, which is half of the speed required when direct drive is employed.

With particular reference to Figure 5, a second embodiment of the invention is shown in which a multi-stage transmission 18 is used which provides greater flexibility in changing the speed of the electrical machine 14 and thus the output voltage, so that optimum engine operating conditions can be maintained, by changing the gear ratio between the engine 12 and the electrical machine 14.

In a modification to the invention, a continuously variable transmission could be used to replace the fixed ratio transmission 18 of the two embodiments described above. The advantage of using a continuously variable transmission is to provide the ability for a smooth change in the voltage generated by the electrical machine 14.

Such a continuously variable transmission could also be controlled by the controller 20 to change the ratio between the engine speed and the input speed of the electrical machine in substantially fixed steps by causing the continuously variable transmission to simulate substantially fixed ratios. This might be appropriate if a sudden increase in torque was needed at the traction motors, for example to overcome a sudden hole in the terrain.

This invention overcomes another problem with hybrid vehicles which arise as a result of the packaging problems of some known electrical machines, which tend to be quite large and heavy. The use of a transmission 18 between the engine 12 and the electrical machine 14 allows the use of high speed electrical machines which are smaller and lighter compared to lower speed machines of similar performance. By gearing up the input speed of the electrical machine 14, high speed electrical machines can become a realistic option, bringing with them advantages for packaging in terms of size and weight. In addition, the overall system traction voltage levels can be raised which, in itself, reduces the currents within the system and has the effect of reducing the power losses in the system and further reducing the size and weight of other components associated with the electrical powertrain, thus improving overall efficiency of the vehicle 10.

It will be appreciated from the above that generally fuel economy and engine noise levels will be primary concerns when considering the desired

input speed presented to the electrical machine by the engine for appropriate performance. However, as suggested above, there can be scenarios particularly in off-road situations where such considerations must be ignored or at least given a lower priority in order for the engine and electrical machine to adequately drive a vehicle. Thus, as described with regard to the present invention, by provision of a set of input speeds for the electrical machine it will be understood that the generator can be rapidly and possibly only transiently shifted to have an input speed for the electrical engine which is inconsistent with the base or long term operational objectives of the controller or generator i.e. fuel economy and/or noise level control, in order to meet a short term objective such as extracting the vehicle or one wheel of the vehicle from a pot hole. Thus, the controller may down or up shift a number of increments of input speed for the electrical machine in order to give an immediate appropriate response in terms of voltage output consistent with current or a previous sequence of operational conditions. In such circumstances, approach of an incline may be detected and greater voltage therefor provided for torque and so traction whilst a decline may result in the input speed to the electrical engine being adjusted to maintain a higher than normal level of engine braking and adjust any regenerative braking through the electrical machine.

It will be understood that the switching between the input speed for the electrical machine will normally be fully automatic and determined by the

controller dependent upon user requirements. However, it will also be understood that for more reactive or user specific response, that the controller may also be specifically over-ridden by the user in order to meet that users requirements with no reference to the base or long term objectives such as fuel economy and noise level control set for the controller.

CLAIMS

1. A generator for producing electrical power, the generator comprising a heat engine arranged in use to drive an electrical machine, wherein the engine is coupled to the electrical machine through a transmission unit which is arranged in use to vary the input speed of the electrical machine with respect to the speed of the engine in order to match the input speed of the electrical machine to provide a power output suitable for prevailing operating conditions and the input speed of the electrical machine being one of a set of input speeds for the electrical machine consistent with pre-determined generator responses to current or a sequence of prevailing operating conditions presented to the generator in order to achieve desired engine efficiency and/or noise level for necessary engine response to generate the input speed for the electrical machine.

2. A generator according to Claim 1, wherein the transmission is arranged to selectively provide an increase in the generator input speed for a given engine speed.

3. A generator according to Claim 1 or Claim 2, wherein the transmission is arranged to effect a substantially stepped change in the input speed of the generator under a predetermined set of conditions.

4. A generator according to any preceding claim, the transmission comprising a continuously variable transmission.

5. A generator according to Claim 4, wherein the transmission is selectively arranged to vary the input speed of the generator in a substantially continuous manner.

6. A generator according to Claim 4, wherein the transmission is selectively arranged to vary the input speed of the generator by simulated substantially fixed ratios.

7. A generator according to any preceding claim, wherein the ratio between the engine speed and the input speed of the electrical machine is controlled automatically by a controller.

8. A generator substantially as described herein with reference to Figures 1 to 4 or with reference to Figures 1 to 3 and Figure 5 of the accompanying drawings.

9. A generator according to any preceding claim comprising a series hybrid powertrain of a vehicle.

10. A controller for a generator according to any preceding claim.

11. A vehicle including a generator according to any one of Claims 1 to 9.

12. A vehicle substantially as described herein with reference to Figures 1 to 4 or with reference to Figures 1 to 3 and Figure 5 of the accompanying drawings.

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Application No: GB 9923231.6
Claims searched: 1-7, 9-11

Examiner: Anthony Guile
Date of search: 25 January 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): B7H (HDE, HXG), G3N (NGE1B), H2H (AF, AG, BCD)

Int Cl (Ed.7): B60K 6/00, 6/02, B60L 11/02, 11/04, 11/10

Other: Online: WPI, EPODOC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2281984 A	(BRITISH GAS PLC.)	
A	EP 0943475 A	(NISSAN MOTOR CO. LTD.)	
X	US 5788004	(BAYERISCHE MOTOREN) See Fig. 5, column 1 lines 41-63, column 2 lines 21-29 and column 2 lines 58-63.	1,2,3,4,5,6 ,7,9,10, 11

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